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The blood-flow velocity analisys as a possible method for arterial calibre discovery. A statistical investigation in 108 human subjects by color-doppler method

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Key words: arterial calibre, blood-flow velocity, echo-doppler.

SUMMARY

Using Echocolordoppler, we have examined 108 subjects with stenosis of the Internal Carotid Artery (ICA). For each subject, age, sex, body weight, height, systolic and diastolic arterial pressure, as well as measures of original caliber of ICA, residual lumen and maximal systolic velocity (MSV) at the stenosis were recorded.

In both sexes there was a highly significant correlation ($p < 0.001$) between MSV, percentage of stenosis, and residual lumen, while there was no correlation between MSV and arterial pressure, which could have modified interpretation of data.

Linear regression analisys was performed to calculate total vessel caliber, whenever not directly measurable, from MSV and residual lumen.

INTRODUCTION

By means of non invasive techniques (echocolor doppler, MNR, X ray-and digital angiography), many morphometrical and structural data have been acquired in the field of cardiovascular anatomy in the last few years. Physiologic variability due to age, sex, body weight, and arterial pressure was evaluated (Macchi et al, 1993). Characteristics and distribution of collateral circulation in the case of arterial stenosis or occlusion (Macchi et al, 1993), as well as the so called physiologic valve incontinence in the heart (Macchi et al, 1994) and in the peripheral veins (Macchi and Catini, 1994) have been documented.

Contemporary use of more techniques allowed anatomo-clinical comparision of results, providing additional information, particularly in the cases of collateral circulation in patients with arterial stenosis, and of the ratio between apparently normal valves and documented physiologic incontinence (Macchi et al, 1993). These anatomo-clinical data in living subjects allowed recording of reproducible measurements in a wide age range of population, with the advantage of avoiding the artifacts of measurements in the cadaver, due to dissection as well as to morphological and structural changes in the tissues.

Echocolor doppler allows highly reproducible quantitative measures, with an accuracy of tenths of millimeters. by means of this rapid, non invasive technique, not only morphological and morphometric characteristics of cardiovascular apparatus can be studied, but also characteristic of blood flow (Franceschi and Jardin-Fauconnet, 1978; Borgatti and De Fabritiis, 1986).

In previous studies, using the same technique, we have dealt of the importance of determining the caliber of the small arteries that may play a significant role in the development of collateral circulation in the case of atherosclerotic stenosis (Macchi and Catini, 1993); a significant correlation between the residual lumen at the level of stenosis and the incidence and importance of neurological deficits was also identified (Weber et al, 1966; Macchi et al, 1994).

The ICA has been one of the most extensively studied vessels, for its hemodynamic importance in maintaining cerebral blood flow (Windle, 1988; Brice et al, 1964; Pastore et al, 1972; Brown, 1982) and determining cerebrovascular diseases (Fazio, 1969; Hennerici and Rautemberg, 1982; Spencer, 1987; La Rosa et al, 1990), also as regard of morphologic and functional variability of the circle of Willis (Elliot-Smith, 1909; Nenci, 1945; Mortillaro e Crivelli, 1963; Fazio et al, 1970; Orlandini et al, 1985). We have recently demonstrated high incidence and clinical importance of kinking of the ICA: incidence of kinking was 38% in total of cases, with a higher prevalence in women; in most cases, the kinking was located in the most distal explorable tract of the ICA, 2-3 cm from its orign (Macchi et al, in press). In the cases, as well as when the vessels are located deep in the soft tissues or under a bone structure (for example the intracranial arteries) or finally, when it is difficult to explore because of the patient's physical conformation, the ultrasound techniques meet a limitation.

Echocolor doppler combines M- and B-mode echotomography (by study of the anatomical structures), with doppler analysis (for measures of blood-flow velocities), and color-code analisys (for analisys of distribution, velocity and direction of blood flow). Combined B-mode and color imaging allows measuring of vessels caliber in the cross-sectional area. However, if the acustic window (that is the possibility of penetration of biological structures by a 2 to 10 MHz ultrasound frequency) is inadequate, B-mode and color imaging are most limited, while doppler velocity analysis are always reliable.

The aim of this study was to validate a reproducible method of calculating arterial caliber from velocity data, whenever direct measures of arterial caliber is difficult or impossible.

MATERIALS AND METHODS

We have examined 108 subjects (54 men and 54 women; age range 58 to 87 years). After we have obtained from each patient an informed consent, each subject underwent echocolor doppler carotid investgation. We have selected the subjects presenting stenosis at the origin of ICA with adequate acustic window. We calculate original vessel caliber and residual lumen by averaging measures by B-mode tomography and by combining B-mode tomography and color doppler analisys. We have measured MSV at the stenosis level by pulsed wave frequency analysis.

For each subject, the following parameters were also determined: body weight (W), height (H), and arterial pressure (AP).

Statistic analysis was performed by calculating the correlation coefficent (r) by linear regression analysis.

The statistical significance of the values of the differences of age, body weight, height, total vessel caliber, percentage of stenosis and MSV at the stenosis level between men and women was evaluated using the Sudent's T test for umpaired groups of samples.

An Acuson 128 XP Echo-Color-Doppler apparatus was used to measure vessel caliber and blood flow velocities.

RESULTS

The characteristic of the subjects are presented in *Table 1* (men) and *2* (women).

The results are follows:

A) males:

1) the **age** was significantly correlated only with systolic AP ($p < 0.05$);

2) the **body-weight** was directly correlated with height ($p < 0.01$) and with diastolic AP ($p < 0.05$);

3) the **height** and the percentage of stenosis were directly correlated ($p < 0.01$;

4) there was a highly significant inverse correlation between **residual lumen**, MSV at the stenosis, and percentage of stenosis ($p < 0.001$);

5) the **original vessel caliber** did not correlate with MSV nor with systolic or diastolic AP, while it inversely correlated with percentage of stenosis ($p < 0.05$);

6) the **MSV** directly correlated with percentage of stenosis ($p < 0.001$), while it did not with AP;

	SEX	AGE	WEIG.	HEIG.	RES.A.	TOT.A.	MAX.V.	MAX.P.	MIN.P.	% STEN.
1	M	58	64	160	2,40	17,80	3,30	160	90	86,50
2	M	58	66	163	3,20	38,20	2,68	120	70	90,30
3	M	59	90	182	8,90	23,00	1,65	155	80	61,30
4	M	60	52	165	9,40	28,60	1,80	150	85	67,30
5	M	61	92	172	5,80	25,80	2,35	180	90	76,60
6	M	62	107	189	6,30	13,10	1,75	160	90	51,50
7	M	64	75	167	3,80	30,50	2,00	160	90	87,40
8	M	64	75	167	2,50	27,10	3,26	160	90	90,90
9	M	64	90	180	7,60	33,10	1,41	150	90	76,80
10	M	66	72	178	9,30	39,20	1,49	150	80	76,30
11	M	67	66	164	6,60	28,70	1,68	140	80	76,90
12	M	67	70	165	6,50	34,10	2,74	180	80	81,10
13	M	68	72	167	2,00	25,30	6,50	220	110	92,20
14	M	68	73	169	12,50	51,70	1,38	150	80	75,90
15	M	68	74	172	3,70	38,20	2,71	130	80	90,30
16	M	69	76	174	6,10	30,30	1,96	150	80	79,80
17	M	69	84	182	10,20	28,00	1,01	155	80	64,10
18	M	69	89	181	6,60	19,80	1,46	130	80	66,50
19	M	70	60	160	10,90	29,30	1,00	180	70	62,90
20	M	70	60	160	9,70	31,60	1,00	180	70	69,30
21	M	70	64	168	4,60	23,70	2,00	150	80	80,40
22	M	70	68	171	7,60	39,10	1,74	160	80	80,60
23	M	70	68	171	2,20	59,80	4,76	160	80	96,30
24	M	70	75	168	5,10	18,70	2,30	150	80	72,60
25	M	70	85	180	10,60	32,60	1,12	160	80	67,40
26	M	71	65	171	5,00	24,10	2,00	150	80	79,30
27	M	72	60	168	8,60	34,50	2,00	160	90	75,10
28	M	72	64	161	5,00	31,50	2,40	180	80	84,10
29	M	72	78	177	10,20	28,50	1,51	150	90	64,40
30	M	73	65	164	4,00	54,20	2,48	150	80	92,60
31	M	73	68	170	4,00	31,20	2,52	130	80	87,30
32	M	73	68	175	8,10	44,20	2,55	140	80	74,80
33	M	73	84	177	3,20	41,40	3,60	165	85	92,30
34	M	74	60	168	7,00	18,10	1,41	170	100	78,10
35	M	74	78	180	7,40	37,20	2,68	140	70	80,00
36	M	75	68	167	10,30	74,70	0,90	170	90	86,30
37	M	75	100	183	3,50	27,30	2,89	180	100	87,10
38	M	76	68	173	5,20	25,40	2,40	160	80	77,60
39	M	76	76	168	7,60	24,90	2,37	160	90	69,70
40	M	76	78	180	16,90	43,00	0,86	160	85	61,30
41	M	77	69	171	10,90	34,30	0,86	145	85	68,30
42	M	77	75	174	3,60	40,80	3,00	170	80	91,10
43	M	78	64	173	6,90	39,20	1,57	150	80	82,50
44	M	79	80	175	12,30	35,80	0,78	195	110	65,50
45	M	79	80	175	4,00	36,80	1,81	195	110	89,00
46	M	81	72	177	7,50	43,90	1,78	160	85	82,00
47	M	81	74	175	3,40	50,60	3,07	145	80	81,40
48	M	82	60	175	5,30	14,60	2,41	160	80	63,70
49	M	82	60	175	6,80	34,10	2,31	160	80	80,00
50	M	83	63	171	10,25	30,75	1,87	150	80	75,00
51	M	83	63	171	3,70	32,40	4,36	160	80	88,60
52	M	84	70	165	4,60	18,80	1,40	220	100	75,40
53	M	84	70	165	4,30	20,90	5,00	220	100	79,30
54	M	84	72	175	3,20	47,00	3,44	150	85	93,20
T	max	84	107	189	16,90	74,70	6,50	220	110	96,30
A	min	58	52	160	2,00	13,10	0,78	120	70	51,50
B	mean	72,04	72,57	171,74	6,61	33,10	2,25	160,83	84,81	78,26
I	sd	7,01	10,70	6,57	3,16	11,54	1,11	20,94	9,31	10,17

	SEX	AGE	WEIG.	HEIG.	RES.A.	TOT.A.	MAX.V.	MAX.P.	MIN.P.	%STEN.
1	F	58	60	157	2,60	27,30	2,90	150	90	90,40
2	F	59	53	168	14,30	52,40	0,73	140	85	72,70
3	F	60	48	160	3,20	17,70	3,36	150	90	82,00
4	F	60	48	160	6,70	34,60	2,40	150	90	80,70
5	F	60	75	163	1,70	23,80	4,66	150	80	91,20
6	F	63	58	160	4,30	23,80	2,43	150	80	81,80
7	F	63	58	160	4,80	24,00	2,37	150	80	80,00
8	F	64	50	148	5,10	31,20	2,54	170	90	83,50
9	F	64	80	170	6,20	43,30	2,20	180	100	85,80
10	F	64	80	170	3,90	30,60	3,26	180	100	87,20
11	F	64	70	158	2,90	30,50	3,90	160	90	90,50
12	F	65	58	165	12,40	38,20	0,78	140	80	67,00
13	F	65	55	160	13,60	42,80	0,56	160	90	67,70
14	F	65	66	156	6,30	24,60	1,72	150	65	74,50
15	F	65	62	153	7,60	34,30	1,37	150	70	78,00
16	F	65	66	156	6,70	34,60	1,92	150	65	80,70
17	F	66	82	174	6,30	13,10	1,76	150	90	51,50
18	F	66	57	164	3,70	20,60	2,10	150	80	82,00
19	F	66	57	161	2,70	32,70	3,36	150	80	91,80
20	F	67	54	163	4,20	12,00	2,47	145	80	65,40
21	F	67	69	176	10,10	37,40	1,42	145	75	73,10
22	F	67	56	157	5,20	27,90	2,24	150	80	81,40
23	F	68	62	167	5,30	34,80	2,65	170	100	84,80
24	F	68	54	159	9,10	99,30	2,00	150	80	90,90
25	F	69	59	174	11,20	35,40	1,04	150	85	68,30
26	F	69	52	158	6,20	35,40	1,90	160	80	82,50
27	F	69	55	163	5,20	39,00	2,46	160	80	85,40
28	F	69	62	154	4,30	29,50	3,00	140	80	85,50
29	F	70	55	160	6,20	20,20	2,39	150	80	69,30
30	F	70	58	163	4,10	29,60	2,84	120	70	86,10
31	F	70	66	165	2,90	31,00	2,82	155	80	90,60
32	F	71	48	158	8,90	29,30	1,22	160	80	69,70
33	F	72	66	158	5,00	35,70	1,92	155	85	86,10
34	F	73	50	146	5,30	14,60	2,41	190	100	63,70
35	F	73	57	168	9,20	46,20	0,90	140	80	79,00
36	F	73	57	160	6,60	35,00	1,40	135	80	81,00
37	F	73	58	152	4,10	17,20	2,50	180	90	76,00
38	F	74	59	158	3,20	19,80	4,80	210	90	83,90
39	F	74	59	162	3,30	30,90	2,94	140	80	89,20
40	F	75	63	160	6,40	37,60	3,80	240	90	83,00
41	F	75	53	155	2,20	19,90	3,60	160	80	89,10
42	F	75	64	163	3,90	40,50	4,00	130	85	90,30
43	F	76	59	167	8,40	32,30	1,59	130	75	74,10
44	F	76	52	159	6,40	27,90	1,76	200	100	76,90
45	F	76	52	159	7,60	37,10	1,45	200	100	79,40
46	F	79	62	163	11,30	37,70	1,00	170	80	69,90
47	F	79	62	163	5,70	21,50	1,53	170	80	72,50
48	F	80	49	155	10,50	36,70	1,00	160	80	71,40
49	F	80	68	161	8,10	34,50	2,10	160	80	76,40
50	F	80	49	155	5,80	25,10	1,98	160	80	76,70
51	F	80	68	161	4,80	44,00	3,59	170	85	89,10
52	F	81	90	160	1,40	34,70	3,40	160	80	95,90
53	F	82	93	154	12,40	36,40	0,86	160	80	66,00
54	F	87	45	150	2,40	30,30	3,63	150	90	92,00
T	max	87	93	176	14,30	99,30	4,80	240	100	95,90
A	min	58	45	146	1,40	12,00	0,56	120	65	51,50
B	mean	70,17	60,51	160,54	6,15	32,16	2,31	158,43	83,61	79,88
II	sd	6,71	10,28	6,09	3,11	12,65	1,02	20,74	8,27	9,10

TAB. III

STATISTICAL CORRELATION (r) IN MALE SEX
Student's T calculation

Males	AGE	WEIGHT	HEIGHT	RES.A.	TOT.A.	MAX.V.	MAX.P.	MIN.P.
AGE		ns	ns	ns	ns	ns	p< 0,05	ns
WEIGHT	0,22		p< 0,001	ns	ns	ns	ns	p< 0,05
HEIGHT	0,09	0,73		ns	ns	ns	ns	ns
RES.A.	0,02	0,01	0,20		ns	p< 0,001	ns	ns
AR. TOT.	0,18	0,14	0,02	0,14		ns	ns	ns
MAX.VEL.	0,08	0,07	0,16	0,72	0,00		ns	ns
MAX.PR.	0,28	0,04	0,22	0,08	0,18	0,25		p< 0,001
MIN.PR.	0,17	0,27	0,07	0,12	0,18	0,18	0,66	
% STEN.	0,10	0,22	0,33	0,71	0,43	0,61	0,03	0,08

7) the systolic and diastolic **AP** were highly correlated ($p < 0.001$);

8) there was no correlation between **diastolic AP** and percentage of stenosis.

B) females:

1) the **age** held no significant correlation with any other variable;

2) the **weight** directly correlated only with height ($p < 0.02$);

3) the **height** directly correlated with weight ($p < 0.01$);

4) there was a significant correlation between **residual lumen**, original vessel caliber, and percentage of stenosis ($p < 0.001$), while residual lumen was correlated inversely with MSV at the stenosis ($p < 0.001$); there was no correlation with systolic and diastolic AP;

5) the **original vessel caliber** did not correlate with MSV nor with systolic or diastolic AP or with percentage of stenosis ($p < 0.05$);

6) the **MSV** directly correlated with percentage of stenosis ($p < 0.001$);

7) systolic and diastolic **AP** were highly correlated ($p < 0.001$);

8) there was non correlation between **diastolic AP** and percentage of stenosis.

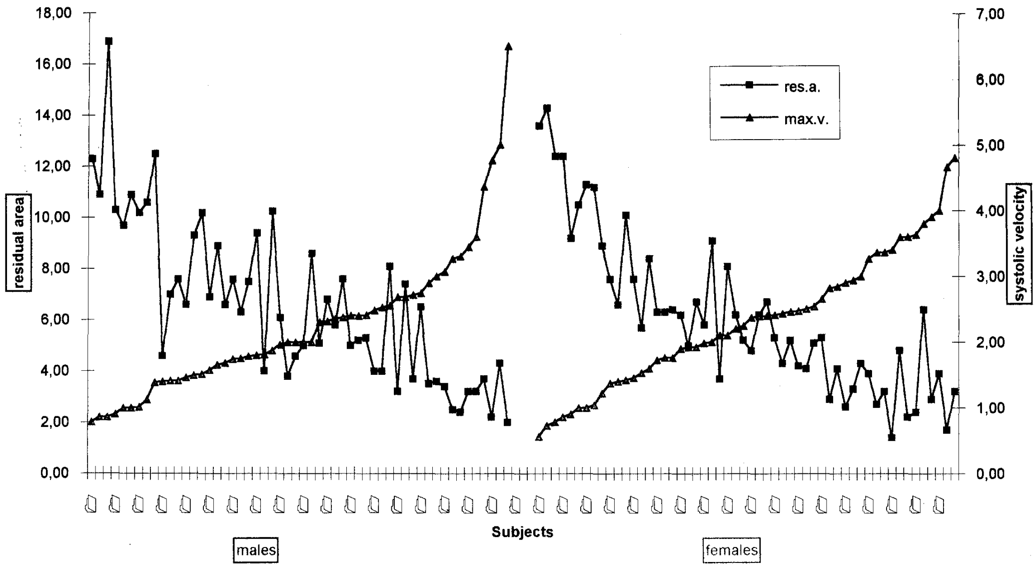
The results of statistical correlations are presented in ***Table 4***.

We then calculated Student's T for umpaired groups, assuming as the zero hypothesis that of not being any differences between men and women in our sample. We could not find differences in age; height and weight were significantly higher in men ($p < 0.001$). There was no significant difference in the two groups as to original vessel caliber, residual lumen, systolic or diastolic AP, MSV and percentage of stenosis.

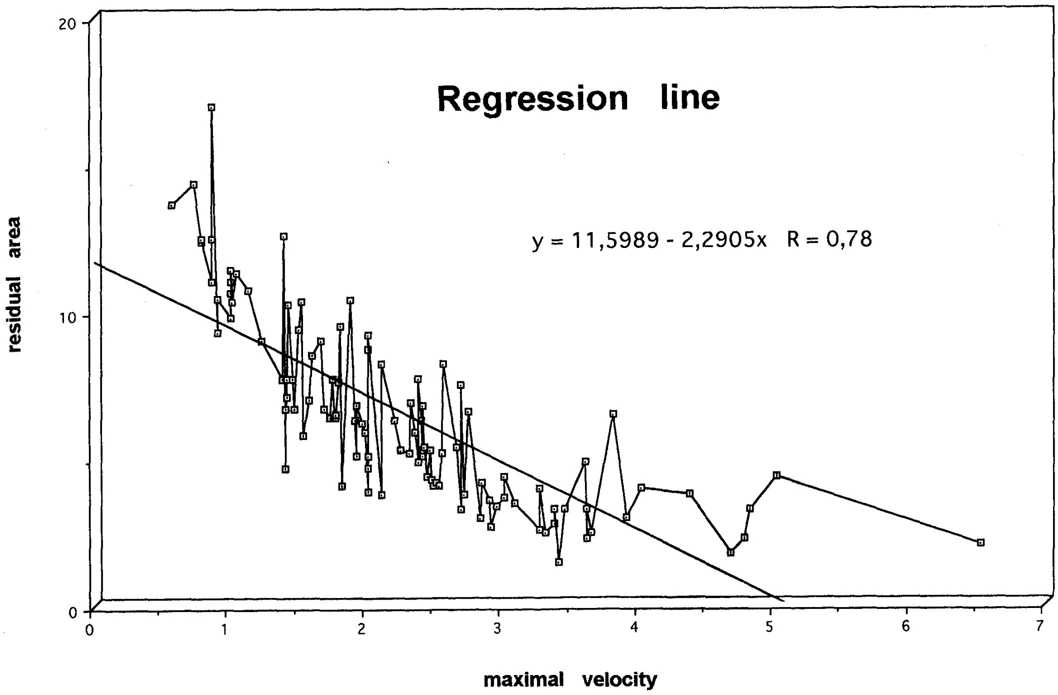
Finally, considering the highly significant correlation between MSV and residual lumen in both sex (*table* 5 and 6), we have calculated the regression line by the equation $y = mx + b$; where the dependent variable y is equal to the residual lumen, and is function of the independent variable x (x = MSV) and of two constant values: m (line slope) and b (y value at the intersection with the ordinate axis). By

TAB IV

VELOCITY and RESIDUAL AREA



TAB V


Regression line
y = 11,5989 - 2,2905x R = 0,78
residual area
maximal velocity
20
10
0
0
1
2
3
4
5
6
7

the formula y = 2.29 x + 11.6, we could calculate the residual lumen from the MSV x (see *fig. 5*).

DISCUSSION AND CONCLUSIONS

The modestly significant correlation between age and AP in our male sample can be explained by the rather old age of the sample (the youngest subject was 57, the mean age was 71,1 ± 6.9).

The relationship between weight and height both in men and women was expected.

An original result is that of the correlation between weight and diastolic AP in men: this results is in accord with the high prevalence of hypertension in the male sex, which on its turn is related to obesity.

In men the correlation body-height/percentage of stenosis is a surprising result, which needs further investigation. The significant correlation between residual vessel lumen and original area was also expressed in our preceding study in which was demonstrated a correlation between the original calibre of the carotid artery and the complication of atherosclerosis (Machi et al., 1993); its exclusive presence in female sex can be explained with prevalence of male vessel calibre respect to female one (Macchi et al., 1993).

The highly significant correlation among residual lumen, percentage of stenosis and MSV, and between MSV and percentage of stenosis in both sexes, allows to obtain the vessel lumen (y) by MSV value with the formula: y = 2.29x + 11.6, where x = MSV: on the other hand, the absence of correlation among AP and MSV, percentage of stenosis, total vessel caliber and residual lumen allows us to apply the equation without taking into account AP: if variation of AP could modify velocities, the calculation of residual lumen from velocity would not have been possible, because higher values of AP would have led to understimate the residual lumen.

The absence of velocity modifications respect to AP variations can be explained with the cerebral autoregulation phenomenon (Agnoli and Bozzao, 1969), according to which carebral vessels dilatate when AP rises, since the increment of cerebro-vascular resistence is directly proportional to the increment of AP, cerebral blood flow remains unchanged.

The increase of cerebrovascular resistance following an increase of AP, causes in turn a decrease of the blood flow velocities, as measurable by doppler analysis (Macchi and Catini, 1993).

In conclusion by doppler analysis, it is possible to calculate residual lumen with good accuracy.

Since our sample was made of patients presenting vessel and pathologic MSV, these results cannot be directly applied to calculation of vessels caliber in the case of normal velocities. The study of normal subjects will be the object of further researchs.

Nevertheless, the clinical importance of our findings lies in fact that in most cases, the need of calculating residual lumen not otherwise directly measurable shows in case of hardly scanning vessels, small or intracranial arteries, kinkings and arterial coilings with high blood flow velocities.

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